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THE EASTERN PACIFIC TROPICAL CYCLONE STRIKE PROBABILITY PROGRAM--ETC(U)
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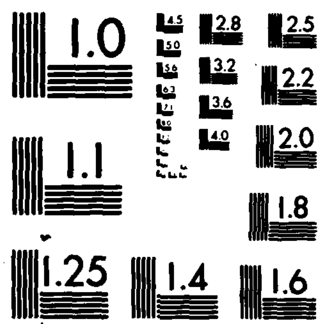

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NAVENVPREDRSCHFAC CONTRACTOR REPORT CR 80-03

LEVEL II

THE EASTERN PACIFIC TROPICAL CYCLONE STRIKE PROBABILITY PROGRAM

Prepared By:

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A system to infer the probability of an eastern Pacific tropical cyclone's striking within an area, given a tropical cyclone forecast, is described. The probabilities are based on an analysis of tropical cyclone forecast errors in the eastern North Pacific.

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Introduction

The Eastern Pacific Hurricane Strike Probability Program (EPSTRKP) is nearly identical in concept to the comparable Western Pacific Strike Probability Program (STRIKP) (Jarrell, 1978)[1]. There are, however, some differences in detail. An earlier study on eastern Pacific tropical cyclones was conducted by W.J. Thompson and R.L. Elsberry (1979)[2]. Thompson and Elsberry subsequently expanded the study to cover the central Pacific (140°W to 180°) and included augmented tracks of those cyclones which recurved over North America. This latter step was considered to be necessary because the earlier geographical distribution of errors appeared to be unrealistically low along the coast. This was attributed to the absence of both forecast positions (since overland dissipation was forecast) and verification positions (actual dissipation) overland, thus only correctly forecast overwater tracks were verifiable. The augmentation of recurvature tracks provided an increase in verifying positions, but made little or no change in the geographical error distribution.

Original Study

Thompson and Elsberry's original study was based on the official forecasts issued by the Weather Service Forecast Office, San Francisco for the years 1971 to 1977. It included only those forecasts in the San Francisco area of responsibility, which represents over 80% of the eastern

[1] Jarrell, Jerry D., Tropical Cyclone Strike Probability Forecasting. NAVENVPREDRSCHFAC Contractor Report CR78-01. December 1978.

[2] Thompson, W.J., and R.L. Elsberry, A statistical analysis of eastern Pacific tropical cyclone forecast errors. Twelfth Technical Con. on Hurricanes and Tropical Meteorology, New Orleans, April 1979.

Pacific tropical cyclones. After the forecasts for the year 1978 were added there were 2036 verifiable 24-hour forecasts.

Thompson and Elsberry also performed discriminant analyses on forecast error. Some of the results of those analyses will be presented in Appendix A.

Augmented Study

Thompson and Elsberry's 1971-78 data base was augmented by extending the postanalysis tracks of hurricanes over North America as far as possible. This was done with the aid of twice per day surface weather charts and satellite mosaics. The former were of limited use because the rough terrain of western Mexico makes interpretation of surface reports in the vicinity of a hurricane exceedingly difficult. The satellite mosaics were the most usable information source except, of course, there is little precision in locating a cyclone center when it has degenerated into a cloud mass over rough terrain. Nevertheless the tracks of those that were extended were reasonably certain.

The original data base was also augmented by adding those forecasts for the central Pacific issued by the Central Pacific Hurricane Center located at the Weather Service Forecast Office, Honolulu.

Statistics for the study before and after track extension and central Pacific augmentation are shown in Table 1.

The extension of overland tracks increased the number of verifiable forecasts from 1% at 24 hours to 6% by

72 hours. This had the net effect of increasing average forecast errors as was expected.

Figure 1 shows average official 24-hour movement forecast errors on a geographical plot. Figure 1b shows the errors for the earlier study forecasts while figure 1a shows the same information after augmentation by extension of over-land verification tracks and the inclusion of central Pacific forecasts. Except for the obvious westward continuation of contours, the two figures are virtually identical.

	24 Hour			48 Hour			72 Hour		
	A	B	C	A	B	C	A	B	C
S-N Error									
Mean	-7	-8	-5	-12	-16	-10	-15	-25	-16
Std. Dev.	87	87	86	154	155	154	213	219	217
W-E Error									
Mean	-6	-7	-8	- 2	- 9	-15	- 6	-30	-33
Std.Dev.	104	104	102	197	200	194	295	310	303
Vector Error									
Mean	115	115	112	215	218	212	312	326	318
Std. Dev.	74	74	73	128	129	130	188	198	198
Corr Coef									
S-N vs W-E	.05	.05	.09	.08	.08	.16	.18	.18	.24
Cases	2036	2058	2327	1276	1309	1541	924	976	1163

Table 1. Evolution of error statistics from 1971-78. Means and standard deviations are in n mi.

A Eastern Pacific
B Eastern Pacific with overland track extensions
C Eastern and central Pacific with overland track extensions.

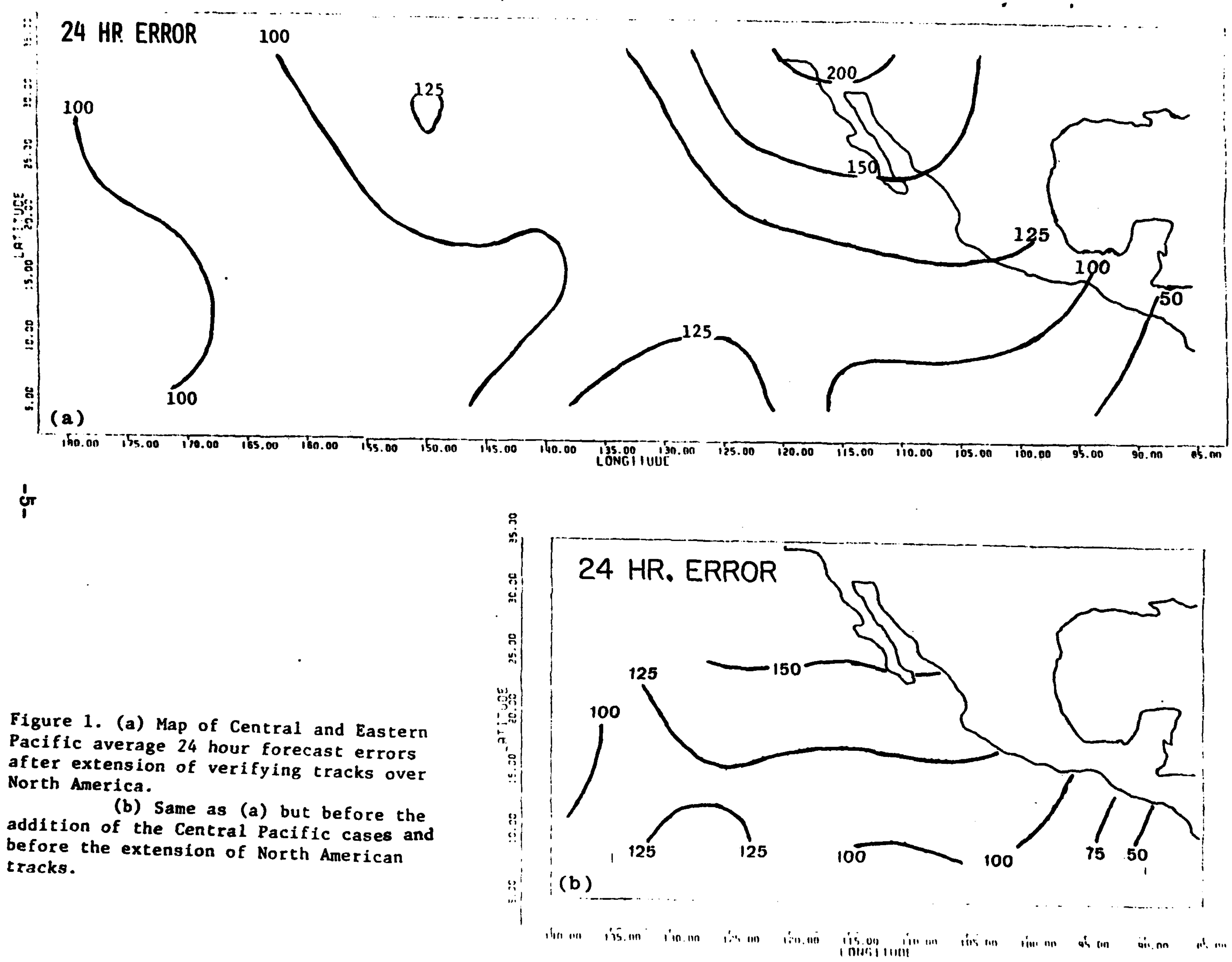


Figure 1. (a) Map of Central and Eastern Pacific average 24 hour forecast errors after extension of verifying tracks over North America.

(b) Same as (a) but before the addition of the Central Pacific cases and before the extension of North American tracks.

The addition of central Pacific forecasts increased the number of verifiable forecasts by 13, 18 and 19% at 24, 48 and 72 hours respectively. The average vector error decreased with the addition of these forecasts, although the bias (component mean errors) remained about the same in magnitude but its orientation became more westerly.

Operational Products

Two distinct strike probability products will be available under operational evaluation during the 1980 hurricane season for the eastern North Pacific.

Product 1. Tropical cyclone strike probabilities for preselected points. This can be disseminated automatically to a distribution list by Fleet Numerical Oceanographic Center (FNOC) via AUTODIN initially and possibly later via the Automated Weather Network (AWN). Included in this product will be a forecast class specification for confidence estimates for the Naval Western Oceanography Center (NWOC) Pearl Harbor (refer to figure 3 of Appendix A).

Product 2. Individual user requests for tropical cyclone strike probabilities via the Automated Product Request (APR) system (AUTODIN only).

Product 1 could be generated routinely by FNOC upon receipt of the NWOC Pearl Harbor tropical cyclone warning every six hours. Product 1 would give the probabilities of a particular tropical cyclone being within 75 n mi (left) or

50 n mi (right) relative to forecast track of nine preselected points of interest. Although subject to change the points currently listed within the program are: Acapulco, Mazatlan, Puerto Vallarta, La Paz, San Diego, Hilo, Honolulu, Johnston Island and Midway Island. The strike probabilities, computed upon receipt of each 6-hourly warning and given at 12-hour intervals after warning time, are presented in two forms. The first is the instantaneous probability, valid at a single instant of time only. The second is a time integrated probability -- the probability that a strike will occur at some time between the effective time of the warning and multiples of 12 hours thereafter. Similarly probabilities of 30 and 50 kt winds are expected to be added to this message at a later date.

Product 2 would be run only upon request. The user would make his request to FNOC via AUTODIN. He would include information sufficient to identify the tropical cyclone, the point of concern (latitude/longitude), and the radii about that point describing the area considered to constitute a strike. The output would be in the same form as in product 1 (i.e., instantaneous and time integrated strike probabilities at 12-hour intervals after warning time).

An example follows to show the user how the output will appear. The example is Tropical Storm ANDRES at 1800 GMT 2 June 1979. At this time ANDRES was 175 n mi south of Acapulco, Mexico with 35 kt winds. It was expected to move northwest at 8 kts for the first 12 hours becoming westerly and finally westsouthwest during June 5th (GMT). Its intensity was expected to increase over the 3-day period to 55 kts.

Two Eastern Pacific Strike Probability Program (EPSTRKP) runs for ANDRES are discussed below.

Run 1 is a FNOC originated run (Product 1) at 02/1800 GMT.

Run 2 is in response to a hypothetical user also at 02/1800 GMT specifying an area within 100 n mi of a point (15°N, 102°W). His request would have gone to FNOC via AUTODIN message as an APR formatted message (see Table 2). Required input is at least one Area of Concern (lat/long) and radii to the left and right of that point (relative to forecast motion).

Tables 3 and 4 illustrate the output from Runs 1 and 2, respectively. These tables also contain some descriptive information.

```
BT
UNCLAS//NO3160//
TROPICAL CYCLONE STRIKE PROBABILITY REQUEST, EASTERN PACIFIC
Q92X0001
/APR,AP(EPSTRKP),(other entries on this line as required)
/STM,NM(ANDRES),NR(EP02), DH(7906021800)/
/AOC,LA(150N),LO(1020W),RL(100),RR(100)/
.
.
.  (as many AOC lines as needed)
.
.
/AAD,
etc.  (as needed)
/PARA,
/ERK/  (required end)
BT
```

/STM: Storm line

NM: Name of cyclone

NR: Cyclone number, Ocean Basin EP = Eastern Pacific

DH: Effective Date/time of warning. (Day 02 hour 1800 GMT) DH(7906021800) = 021800Z June 1979

/AOC: Area of concern line

LA: Latitude of point of concern. LA(150N)=15.0° north.

LO: Longitude of point of concern. LO(1020W)=102.0° west.

RL: Radius of area of concern to left of storms track.

RR: Radius of area of concern to right of storms track.

Usually RL is greater than RR. Default values of 75/50 nm will be used if both RL and RR are zero or blank.

Note: One input record will be written for each /AOC (including storm information). Request message in accordance with FLENUMOCNCEN, 1977: ASWOCAS Request Procedures Manual, Vol. 2.

Table 2. Sample Automated Product Request (APR) System Message.

Run 1 Output (Product 1)

```
STRIKE PROBABILITY FORECASTS
ANDRES  021800Z
ACAPULCO     00ININ*120815 240418 360218 480119 600119 720119
MAZATLAN     00ININ 12ININ 24ININ 36ININ 48ININ 60IN01 72IN02
P VALLRTA    00ININ 12ININ 24ININ 360101 480104 600106 720107
LA PAZ       00ININ 12ININ 24ININ 36ININ 48ININ 60ININ 72IN01
SAN DIEGO    THREAT NIL*
HILO         THREAT NIL
HONOLULU     THREAT NIL
JOHNSTN I    THREAT NIL
MIDWAY I     THREAT NIL
FOR NWOC PEARL..CLASS = THREE
PROBABILITIES BASED ON FOLLOWING FORECAST
001400989035 121481004040 241501020045 481421049050 721321070055

FORECASTS: Time 12 hr Latitude 14.8N Longitude 100.4W Max Wind 40 kt
```

LAT/LONG of preselected points are stored within program. Strike is predefined to occur if tropical cyclone passes within 75 n mi radius (left) or 50 n mi radius (right) of track of tropical cyclone.

---

*THREAT NIL means all probabilities for this station were <0.5%. IN means insignificant (<0.5%).

Table 3. Output from Run (1).

Run 2 Output (Product 2)

```
STRIKE PROBABILITIES FOR TROPICAL CYCLONE ANDRES
FROM 021800Z BASED ON FOLLOWING FORECAST
001400989035 121481004040 241501020045 481421049050 721321070055
STRIKE IS BEING WITHIN 100NM RIGHT AND 100NM LEFT OF 15.0N 102.0W
STRIKE PROBS 000202 123840 243143 361443 480743 600443 720343
```

TIME

PROB(%) that ANDRES will be in area at 051800 (Warning time + 72 hours) was 3%

PROB that ANDRES will be in area some time between 021800Z and 051800Z (72 hour period) was 43%.

ABBREVIATIONS:

Number 01-99; strike probability in %

IN = insignificant; p<0.5% Prevents representation of 0% and 100% which occur only as an approximation.

The input forecast data is error checked only in that the tropical cyclone forecast motion is computed between forecast points. If vector motion deviates substantially from the climatological mean, the following warning message will appear in all products:

*** UNUSUAL MOTION -- PLEASE RECHECK WARNING DATA ***

TABLE 4. OUTPUT FROM RUN (2).

APPENDIX A

Discriminant Analysis

The discriminant analyses routine of the UCLA BIOMED (Dixon, 1975)[1] series was run on the data to develop functions to discriminate on forecast error. Predictands were forecast error group numbers 1, 2 and 3. The groups were determined by using in turn the 24-, 48- and 72-hour forecast errors to split the forecasts into three equal groups according to error magnitude; group 1 had the smallest errors and group 3 the largest. Table A-1 shows average forecast errors for the three error classes, where the classes were imperfectly discriminated by applying functions developed on each of the predictands. If discrimination were perfect, the groups and classes would be identical.

Applied to:	24 hr errors			48 hr errors			72 hr errors		
Class:	1	2	3	1	2	3	1	2	3
Used for Split:									
24-hour errors	88	107	138	185	214	252	280	335	371
48-hour errors	95	98	132	174	194	265	266	301	402
72-hour errors	95	94	128	176	187	255	265	288	393

Table A-1. Average movement forecast errors for 24, 48 and 72 hours classed by discriminant functions. The functions were derived on forecasts of one time length, but applied to the other lengths.

Based on the difference in group means, the discrimination provided by the functions developed on 48 hour errors (underlined) is superior to the other two. There is generally poor discrimination between classes 1 and 2 as evidenced by the closeness of their means. Class three, the difficult forecast, appears to be well separated from the other two classes.

Eight predictors were selected from 23 candidates. Table A-2 defines the eight predictors, gives their means, standard

[1] Dixon, W. J., BMDP biomedical computer programs. University of California Press, Berkeley, 1975.

	Predictor	means Class 1	2	3	std dev 1	2	3		Function 1 Coef	Function 2 Coef
1	DIRECTION	280.0	277.0	282.0	47.6	55.4	57.9		-.005	.007
2	LATITUDE	15.3	15.2	15.8	2.72	2.63	2.77		-.104	.105
3	MAX WIND	65.9	67.4	61.9	23.8	25.2	21.4		.015	-.021
4	ADJ DIR	179.0	180.0	188.0	22.4	27.1	31.6		-.015	.012
5	FIX ACCY	25.1	26.1	28.3	8.01	8.73	9.91		-.058	-.008
6	$(JD-\overline{JD})^2/100$	11.0	13.5	14.9	13.7	16.3	17.4		-.020	-.021
7	ADJ LONG	14.4	11.6	10.6	11.0	9.3	8.3		.043	.070
8	N. COMP	1.95	2.07	2.46	1.47	1.49	1.73		-.314	.092
								Const	6.719	-4.950

Table A-2. Discriminant function predictors. Class means and standard deviation of each are given. Also shown are the coefficients for each predictor which define the two functions.

Predictor definitions:

1 Direction of cyclone 12 hour predicted motion in degrees clockwise from north
2 Latitude in degrees north of the equator
3 Maximum wind reported in the forecast in knots (nowcast wind)
4 Direction-110 or if Direction is <110, direction + 250. Places 0-360 discontinuity at 110°T
5 An average initial warning position error based on fix basis in n mi
6 Square of deviation of Julian Date from mean (227), scaled x 0.01
7 Absolute deviation of longitude from mean (119°W)
8 Absolute deviation of northward component of motion (see 1) from mean (3 kts)

deviations and the coefficients that define the discriminating functions. A close examination of Table A-2 suggests less than optimum conditions for discriminant analysis. Some of the predictors are clearly not normally distributed, (i.e., direction is strongly bimodal), some are closely related (direction and adjusted direction). These are not serious since the worst offender, direction, is one of the least significant predictors (see diagram at the origin of figure A-1 where length of the vector relates to predictor contribution to error discrimination). Other aspects of the discriminant analysis that might appear questionable are the small differences in predictor means. Sample size was 2327 cases so each class has on the order of seven hundred cases. Differences in means of 1.96St.Dev./$\sqrt{N}$ are significant at the 5% level, which means differences greater than 0.07S are significant. For example, the standard deviation for variable #8 is about 1.5 kts, therefore differences in the mean of .11 kts would be significant. The actual differences are .12 kts and .51 kts between the class 1 mean and the other two and .39 kts between classes 2 and 3, all are significant. Of course not all the differences in the means are significant at the 5% level, but most are.

One comparable way to look at the differences in standard deviations is to perform the same test on the means as above, but use each of the class standard deviations. Intuitively, if there is no difference in the outcome, the difference in the standard deviations is not important. There are very few comparisons where the outcome depends on which of the three standard deviations is used.

Figure A-1 shows an x-y space with function 1 on the x-axis and function 2 the y-axis. The values of these functions

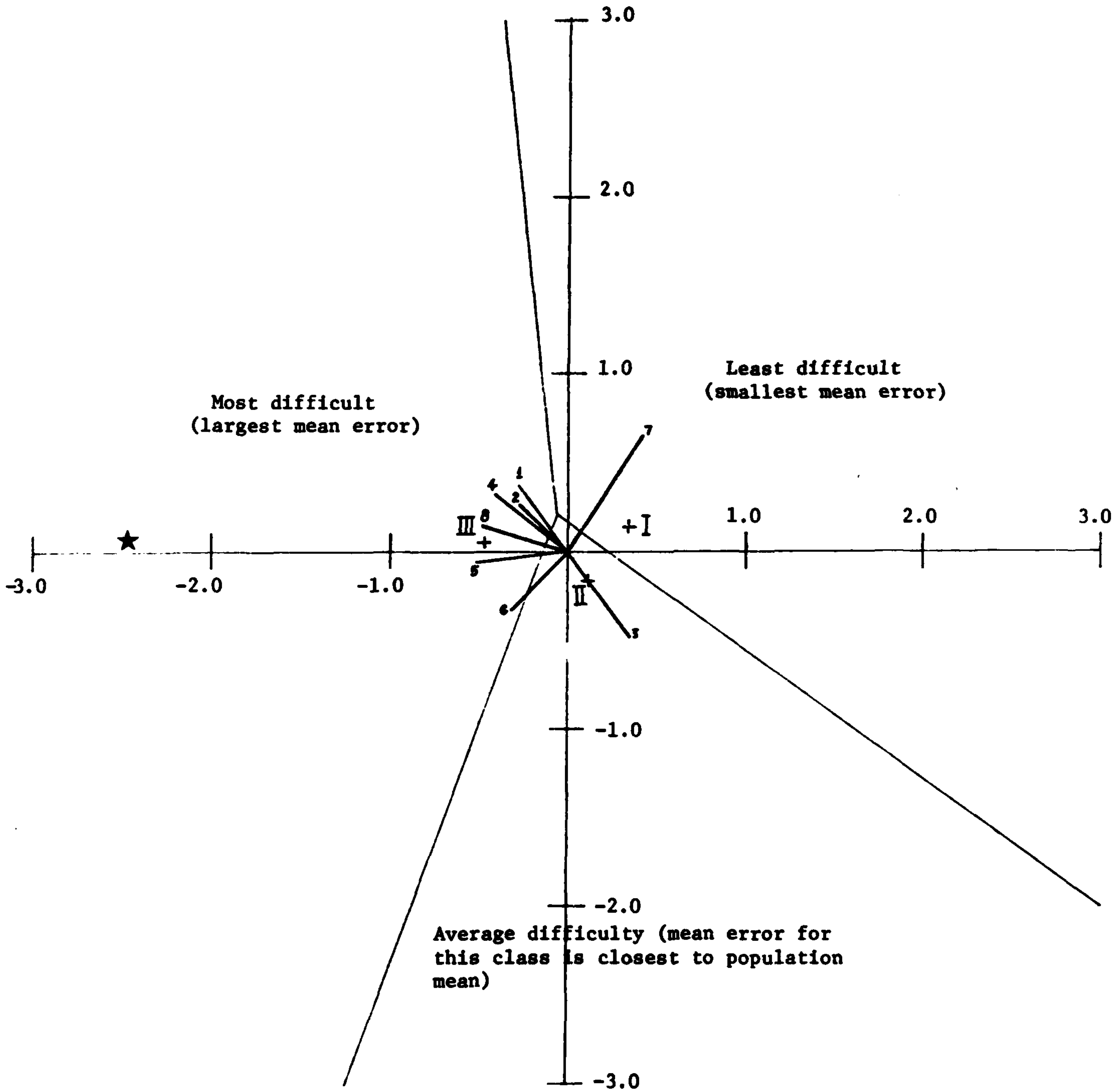


Figure A-1. Function 1 vs Function 2 in x-y space. +'s show location of intersection of functions evaluated at the three class means. The space is partitioned according to class. The diagram at the origin depicts the effect of an increase of one standard deviation in each of the eight predictors. Star refers to Tropical Storm ANDRES on 2 June 1979 at 1800 GMT. (See sample output, Table 3 of text.)

have been evaluated at the group mean for each predictor (see Table A-2). These mean points are plotted, and the space is divided into three areas whose member points would be nearest to the included mean point. Since there is little difference in class 1 and 2, the far left of the diagram is the difficult area, with the right and center the average forecasts. The origin represents the two functions evaluated at the population mean, versus class mean, of each predictor.

The diagram at the origin represents the effect of one predictor alone being increased by one standard deviation. This provides some insight into the causes of forecast difficulty in EASTPAC. See for example the effect of a deviation of predictor 5, Fix Accuracy. This is actually the mean warning position error for all warnings based on combinations of methods used to locate the center (aircraft, satellite, radar, etc.). While the mean error is around 25 n mi, the worst method, extrapolation alone, has a 50 n mi average error, which is about 3 standard deviations away from the mean. Notice in figure A-1, three lengths of the small vector labeled 5 moves a forecast from the average into the difficult (class three area) forecast region by a large margin.

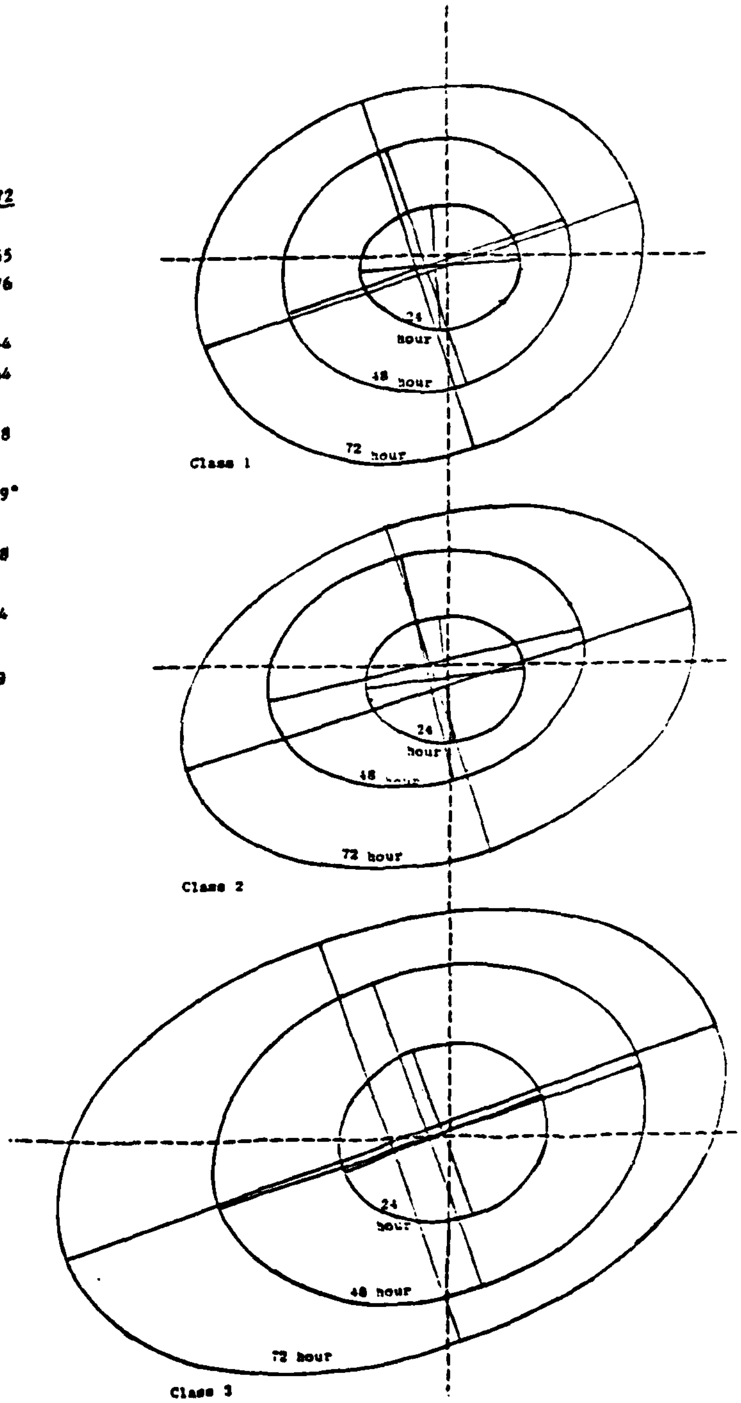
The star in figure A-1 represents an actual computation of Function 1 (x=-2.47) and Function 2 (y=0.60) for tropical storm ANDRES on 2 June 1979. (ANDRES was discussed as the output example in the operational products section of this report). We expect this is a difficult forecast and will likely have a large error. The discriminant analysis predictors and basic variable are given below as are the terms of Function 1 (x) and Function 2 (y).

	Basic Variable		Predictor	Function 1	Function 2
1	Direction	NW=315°	315°	-1.58	2.21
2	Latitude	14°N	14°	-1.46	1.47
3	Max wind	35 kt	35 kt	0.53	-0.74
4	Adj dir	315-110	205°	-3.08	2.46
5	Fix acy	Sat/Extrap	43.5 n mi	-2.52	-0.35
6	Jul date	153	54.76	-1.10	-1.15
7	Adj Long	98.9°W	20.10°	0.86	1.41
8	North mvmt	5.66 kts	2.66 kt	-0.84	0.24
			Constant	6.72	-4.95
				-2.47	0.60

Generally the terms which are contributing to the forecast difficulty are those where Function 1 is negative (direction, both terms, and fix accuracy) and to a lesser extent those negative terms in Function 2 which are not of consequence here.

Figure A-2 shows plots of 24-, 48- and 72-hour unit probability ellipses. A point on a unit ellipse is one standard deviation away ($\pm$) from the mean in one coordinate when the other is at the mean. A unit probability ellipse is equivalent to a 39% probability ellipse.

Forecast (hours)	Class 1 24	Class 1 48	Class 1 72	Class 2 24	Class 2 48	Class 2 72	Class 3 24	Class 3 48	Class 3 72
W-E error									
mean	-12	-22	-30	-4	2	-9	-8	-24	-65
std dev	88	157	247	92	177	284	116	237	376
S-N error									
mean	-13	-13	-16	-16	-24	-28	6	7	-4
std dev	70	132	191	71	134	198	102	186	264
W-E and S-N Correlation	.03	.12	.18	.06	.14	.26	.13	.20	.28
Orientation of Major Axis	4°	17°	17°	6°	13°	17°	21°	19°	19°
Length of Major Axis	88	159	253	92	179	292	119	243	388
Lengh of Minor Axis	70	130	183	71	131	187	99	177	244
Area (10^4 nmi^2)	1.9	6.5	14.6	2.0	7.4	17.1	3.7	13.5	29.9



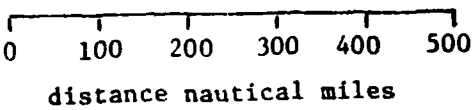


Figure A-2. Unit probability ellipses of forecasting errors from three forecast difficulty classes at 24, 48 and 72 hours. The class parameters are given in the inset table. **The origin is the forecast position.**

The three nested sets represent the three classes of errors. The nested ellipses represent in increasing size the 24-, 48- and 72-hour forecast. The class 2 ellipses are larger than those of class 1 but the difference is small. In general the class 3 ellipses are similar in shape and orientation to those of classes 1 and 2 but corresponding ellipses are roughly twice as large (in area). The inset table summarizes the ellipse parameters.

The discrimination can be contrasted to that reported by Nicklin (1977)[2] for the western Pacific. In that case the 24-hour errors were far better discriminated, but the 72-hour errors were not discriminated as well. It can be seen from Table A-1 that if the 24-hour error had been used as the basis for discrimination (as it was in the western Pacific) the effect would have been to make the results more similar. The 48-hour discrimination is about the same in both ocean basins. One difference is that in the western Pacific the less difficult third of the forecasts were well separated from the remainder whereas in the eastern Pacific the most difficult third of the forecasts are more easily isolated. Overall, the discrimination appears slightly better in the eastern Pacific, perhaps because of the inclusion of information relative to initial position accuracy (see variable 5, Table A-2).

Forecast confidence estimates can be inferred for each forecast class. These can either be expressed as a percentage of occasions when the actual forecast error will

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[2] Nicklin, Donald S., A Statistical Analysis of Western Pacific Tropical Cyclone Forecast Errors, M.S. Thesis, U.S. Naval Postgraduate School, Monterey, CA, June 1977.

lie between zero and some set distance (i.e., the probability the error is less than 100 n mi) or as a distance which will exceed the actual error with a set probability (the radius of a 75% probability circle). Figure A-3 presents this probability information for 24-, 48- and 72-hour forecasts (curves left to right) and for classes 1, 2 and 3 (top to bottom). For example 200 n mi represents the radius of 95%, 57% and 30% probability circles for class 1 24-, 48- and 72-hour forecasts respectively. Similarly the 80% confidence limit on class 2 forecast errors is 153, 296 and 465 n mi at 24, 48 and 72 hours respectively.

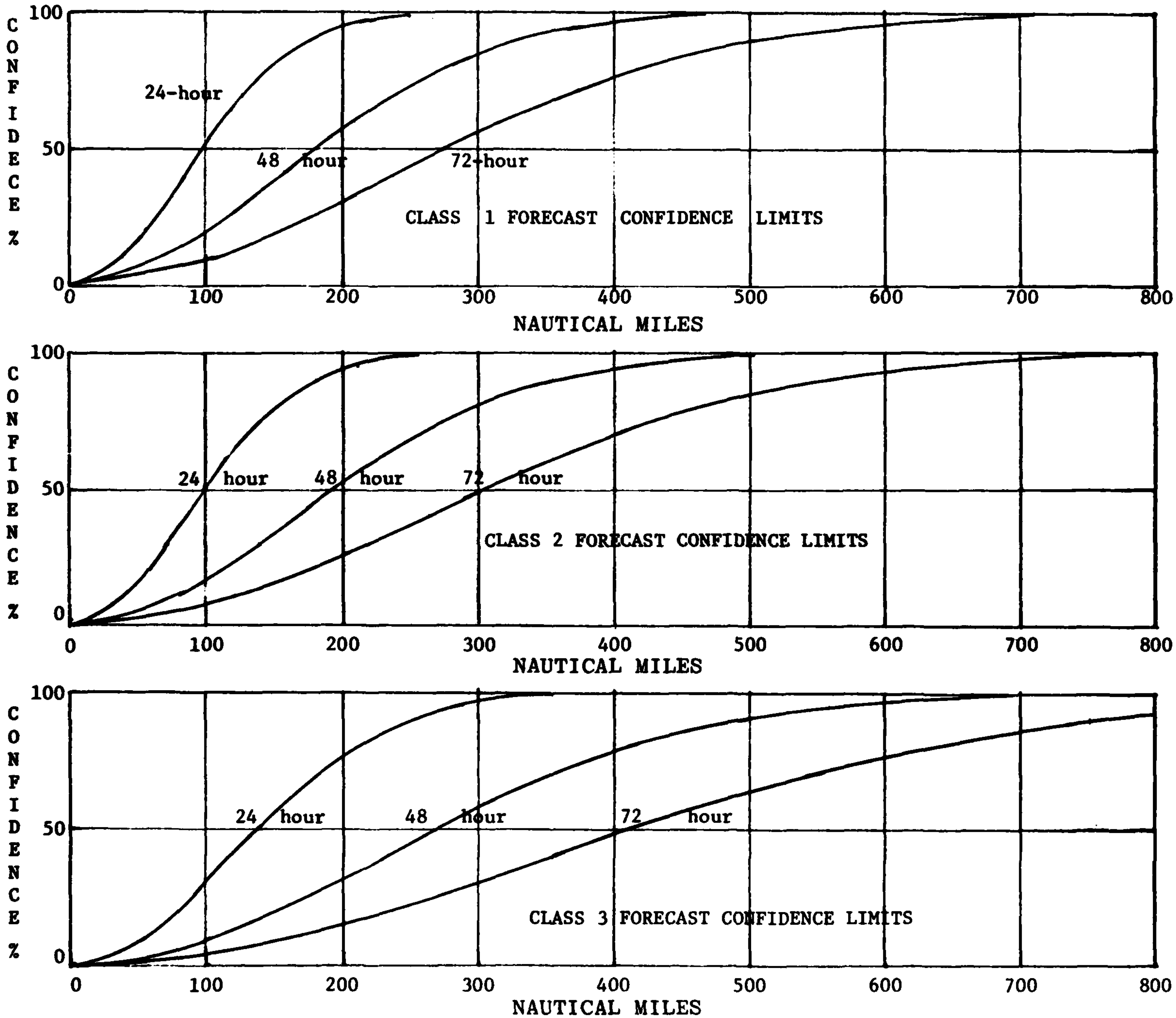

Figure A-3. Confidence limits on eastern Pacific hurricane forecast accuracy by class top to bottom.

Distribution List

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